From: Jones, Anthony
To: Bergman, Aaron
Cc: Adamantiades, Mikhail; Kislear, Jordan
Subject: RE: Carbon Capture Using Fuel Cell Power Plants
Date: Wednesday, April 05, 2017 8:10:51 AM

Aaron,

Per your suggestion I have reached out to Jordan Kislear regarding the email below. Jordan said he would provide me a couple URL links to assist in developing a response.

Thanks,

Tony

Anthony L. Jones
Environmental Engineer
OAR/OAP/Clean Air Markets Division – Program Development Branch
U.S. Environmental Protection Agency
1201 Constitution Avenue, NW
Washington DC 20004
Phone: 202-343-9088
Email: jones.anthony@epa.gov

From: Jones, Anthony
Sent: Thursday, March 30, 2017 9:58 AM
To: 'aaron.bergman@Hq.Doe.Gov' <aaron.bergman@Hq.Doe.Gov>
Cc: Adamantiades, Mikhail <Adamantiades.Mikhail@epa.gov>
Subject: FW: Carbon Capture Using Fuel Cell Power Plants

Adam,

Misha provided your contact information to me. I am forwarding to you an email thread. The email below concerns relative spending in advancing carbon capture technology vis-à-vis other alternatives (e.g., wind, solar, etc.). In a brief discussion with Misha I stated I think solar and wind are relatively mature technologies that are being installed in utility-scale projects. Carbon capture is still very much on the drawing board.

Misha thought you might be able to provide information on how much the federal government is spending on researching carbon capture as compared to other technologies. Please let me know if you can respond to the attached email. Also, please copy Misha and I on the response.

Here is the contact information for Dr. Michael Kerby (Manager, Corporate Strategic Research):

ExxonMobil Research and Engineering Company
1545 Route 22 East, East Clinton Township
Annandale, New Jersey 08801
Telephone: 908-335-2838
Email: Michael.c.kerby@exxonmobil.com

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From: Kerby, Michael C [mailto:michael.c.kerby@exxonmobil.com]
Sent: Thursday, March 30, 2017 7:57 AM
To: Jones, Anthony <jones.anthony@epa.gov>
Subject: RE: Carbon Capture Using Fuel Cell Power Plants

Tony: sounds good.

One question that has come up is the relative spend in research $'s for advancing carbon capture technology vs other alternatives (such as wind, solar, etc). I've heard numbers that the amount of $'s supporting alternative technology is on the order of >300 times that of carbon capture technology. Was just curious if you had any information on this? Thanks, Mike

Michael (Mike) C. Kerby
908-730-2838
908-625-1263 (cell)

From: Jones, Anthony [mailto:jones.anthony@epa.gov]
Sent: Wednesday, March 29, 2017 9:00 AM
To: Kerby, Michael C <michael.c.kerby@exxonmobil.com>
Subject: RE: Carbon Capture Using Fuel Cell Power Plants

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Subject: RE: Carbon Capture Using Fuel Cell Power Plants

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Sent: Tuesday, March 28, 2017 2:44 PM
To: Kerby, Michael C <michael.c.kerby@exxonmobil.com>
Cc: Leo, Tony <tleo@fce.com>
Subject: RE: Carbon Capture Using Fuel Cell Power Plants

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Please contact me if there are any errors in this email, or if you have any questions or concerns.

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Email: jones.anthony@epa.gov

From: Jones, Anthony
Sent: Thursday, March 23, 2017 10:25 PM
To: OAR-OAP-CAMD-PDB <OAROAPCAMDPDB@epa.gov>
Cc: Hutson, Nick <Hutson.Nick@epa.gov>; DeFigueiredo, Mark <DeFigueiredo.Mark@epa.gov>; 'Rosner, David' <David.Rosner@Hq.Doe.Gov>; 'Litynski, John' <John.Litynski@Hq.Doe.Gov>
Subject: Carbon Capture Using Fuel Cell Power Plants

Attached is a PDF file (see *Carbon Capture Presentation @USEA(16Mar 2017).pdf*) that contains a presentation on carbon capture with fuel cell power plants. This presentation was made on 16 Mar 2017 by Dr. Michael Kerby (ExxonMobil) and Mr. Tony Leo (FuelCell Energy) at the United States Energy Association (USEA) offices in Washington DC.

This presentation concerns using a modified Molten Carbonate Fuel Cell (MCFC) to capture carbon dioxide (CO2). Conventional carbon capture typically consumes about 20 percent of a power plant's energy output. Fuel cells have the potential to not only avoid this "parasitic loss," but to generate power while capturing CO2 emissions. Page 16 of the attached PDF states the potential exists to capture 90 percent of the CO2 emitted by a typical 500-megawatt (MW) natural gas-fired power plant while generating an additional 120-MW of power. There is also the potential to make up to 150 million cubic feet per day (ft^3/day) of hydrogen. FuelCell Energy (FCE) also indicates on its website that capturing 90 volume percent of the CO2 in the flue gases from a 500-MW coal-fired power plant would increase power output by 80 percent to 900-MW, with a cost of electricity at $0.08 per kilowatt-hour.

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Fuel cells do NOT burn fuel. Fuel cells use an electrochemical process to convert potential chemical energy from hydrogen-rich fuels into electricity and heat.

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Page 8 of the presentation provides another graphical representation of the electrochemical process. Flue gas from a coal-fired Electrical Generating Unit (EGU) typically has a high-volumetric flow with a relatively low CO2 concentration. Flue gas will be fed to the MCFC and the CO2 in the flue gas will transfer across the fuel cell membrane from the air electrode chambers to the fuel electrode chambers. Because the natural gas volumetric feed rate is much lower than the flue gas volumetric flow rate, the CO2 concentration in the gas exiting the fuel electrode chambers will increase to about 70 volume percent. The balance of the gas being discharged from the fuel electrode chamber will be primarily hydrogen. Separating CO2 from hydrogen is a much less energy intensive process than separating it from air/oxygen. The treated gases will be suitable for storage in a geological formation or further processing.

Note that FCE's power plant modules also include desulfurization equipment (if needed to control sulfur in the flue gas), water treatment equipment (the process consumes and discharges water), electrical balance of plant (EBOP), and mechanical balance of power (MBOP). For example, the EBOP converts the direct current (DC) produced by the MCFC to alternating current (AC) power. Further details are provided in the attached MS Word file (see *Carbon Capture w MCFCs (23 Mar 2017.docx*).

An additional benefit from using the MCFC to capture CO2 is that a separate reaction in the MCFC destroys about 70 volume percent of any nitrogen oxides in the flue gas. In addition, the process generates heat energy that can be used to heat water or for space heating.

"DoE Funded Pilot"

The Department of Energy (DoE) has provided funds to conduct the first MW-scale pilot testing using MCFCs for carbon capture. FCE plans to test a modified 2.8-MW MCFC at Southern Company's Plant Barry, which is located near Mobile AL. The modified 2.8-MW MCFC will be tested on a "slip stream"

taken from one of Plant Barry's coal-fired EGUs. After modification for carbon capture, the modified 2.8 MW MCFC will only produce about 2-MW of electricity. The modified 2.8-MW MCFC will be capturing the equivalent of the flue gas that would be exhausted by a 3-MW coal-fired unit. This testing is tentatively scheduled for Oct 2018 to Mar 2019.

ExxonMobil is collaborating with FCE to conduct testing at Plant Barry using flue gas from a natural gas-fired source. The details of this testing (e.g., flue gas source) have not been finalized to date. This testing will take place following completion of the test using the coal-fired EGUs "slip stream."

"Stack Replacement"

This severe, high temperature service requires that the fuel cell stack be refurbished every five years. FCE has recently developed MCFCs using nickel and stainless steel that can go up to seven years without refurbishment. FCE's modular design allows for removal of the MCFC for refurbishment and replacement with a new MCFC.

"Scaling Up"

If the pilot plant testing is successful, FCE will determine if it can "scale up" using the modified MCFC. Page 11 shows that twelve 280-MW MCFCs would create about a 3-acre footprint (510 feet by 240 feet). This arrangement could be used to capture 90 percent of the CO2 in the flue gas generated by a 35-MW coal-fired EGU, or for a lower CO2 capture rate on a larger coal-fired EGU.

If the MCFC pilot trial at Plant Barry is successful, FCE believes it can achieve a carbon capture cost at or below $40 per metric ton of CO2 captured.

Please review the attachments and contact me if you have any questions.

Thanks,

Tony

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OAR/OAP/Clean Air Markets Division – Program Development Branch
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1201 Constitution Avenue, NW
Washington DC 20004
Phone: 202-343-9088
Email: jones.anthony@epa.gov

From: Jones, Anthony
To: Kerby, Michael C; Leo, Tony
Cc: Kislear, Jordan
Subject: DoE R&D Spend for Carbon Capture and Storage
Date: Tuesday, April 25, 2017 6:57:12 PM

Mike/Tony:

Sorry for the delay in providing the information you requested regarding federal funding of Research and Development (R&D) for carbon capture technology versus other technologies. The best source for this information is the Department of Energy's (DoE's) Fiscal Year (FY) 2017 Congressional Budget Request (see https://energy.gov/sites/prod/files/2016/02/f29/FY2017BudgetVolume3_2.pdf). Page 7 of 822 in the PDF file provides a breakdown of FY2017 DoE funding requests by appropriation (in $1,000). The Energy Efficiency and Renewable Energy (EERE) program requested FY2017 funding of $2,898,400,000 and the Fossil Energy (FE) R&D program requested FY 2017 funding of $600,000,000. (The $600,000,000 includes $240,000,000 from prior year balances.)

Page 15 of 822 in the PDF file breaks down EERE funding in FYs 2015, 2016, and 2017. EERE serves as the federal government's principle clean energy advocate. EERE's main function is to research, develop, demonstrate, and deploy innovative technologies while simultaneously working to remove market barriers in sustainable transportation, renewable power, and energy efficiency.

Page 559 of 822 in the PDF file provides FE R&D funding for FYs 2015, 2016, and 2017. FE R&D leads federal research, development, and demonstration efforts on advanced Carbon Capture and Storage (CCS) technologies. One of FE R&D's key goals is to demonstrate that electric generation technology with CCS can be safely and reliably deployed at commercial scale. For this reason, the FE R&D portfolio includes several different technological approaches and applications of CCS. In addition, the US and 19 other countries have launched a "Mission Innovation" to accelerate clean energy technology innovation and cost reduction. $564 million of FE R&D's aforementioned FY2017 Budget Request of $600 million is to support "Mission Innovation." Page 560 of 822 discusses in detail how DoE has restructured the FE R&D to drive innovation and eliminate categorization by fuel type. The budget line has been renamed from "Coal/CCS and Power Systems" to "CCS and Advanced Power Systems." Examples of FE R&D projects designed to provide clean, affordable energy while augmenting the US's energy security include:

1. Prioritizing post-combustion and pre-combustion carbon capture for fossil-fueled power plants with a new emphasis on reducing costs and addressing technical challenges associated with natural gas carbon capture.
2. Advanced Combustion Systems that focus on developing technologies such as pressurized oxy-combustion and chemical looping processes that facilitate carbon capture.
3. Initial funding for one additional (three total) post-combustion large pilot projects (10+ MWe).
4. New Natural Gas Carbon Capture to support a Front End Engineering and Design (FEED) study for, and initial construction of, one large pilot plant specifically designed to capture carbon dioxide (CO_2) from a natural gas power plant.
5. The Advanced Combustion Systems subprogram will also fully fund two additional (four

total) FEED studies:

   a. One chemical looping (two total); and
   b. One oxy-combustion (two total).

6. Funding to accelerate the discovery of transformational carbon capture technologies for both pre- and post-combustion capture systems for coal and natural gas.
7. Continued funding for field testing carbon capture systems at the National Carbon Capture Center near Wilsonville, Alabama.
8. Rebalancing the Carbon Storage subprogram portfolio to move from the large-scale injection operations in the Regional Carbon Sequestration Partnership (RCSP) to support for:
   a. On-shore and off-shore characterization and technology validation efforts;
   b. Commercial-scale site characterization and Brine Extraction Storage Test (BEST) field activities; and
   c. Lower-cost post injection monitoring technologies at RCSP field sites.

Page 566 of 822 in the PDF file requested approval for the following FY2017 expenditures within the FE R&D budget:

- Carbon capture budget of $170,352,000;
- Carbon storage budget of $90,875,000;
- Advanced Energy Systems budget of $47,800,000; and
- Crosscutting Research and Analysis budget of $59,350,000.

Note that fuel cells are funded in EERE under budget line "Hydrogen and Fuel Cell Technologies," which is a $105,500,000 program. (See page 22 of 822 in the PDF file). Page 80 of 822 provides additional detail for a "Fuel Cell R&D" budget line and documents actual and requested funding for FYs 2015, 2016, and 2017. The FY2017 fuel cell R&D budget line funding request is $35,000,000. Note that EERE focuses on R&D for Polymer Electrolyte Membrane (PEM) and other fuel cell technologies. FE R&D concentrates on solid oxide fuel cell development. Pages 570, 573, 576, and 579 of 822 in the PDF file document actual and requested funding for "solid oxide fuel cells." The FY2017 "solid oxide fuel cells" budget line funding request is $8,000,000. (See page 579 of 822 in the PDF file.)

I am not sure what the basis is for the statement that the federal government is spending $300 on R&D for alternative technologies for every dollar it spends on carbon capture technology R&D. There are literally hundreds of permutations that can be used to compare total federal government carbon capture R&D spend against alternative control R&D spend. Which fiscal year? What constitutes carbon capture? What constitutes carbon storage?

For the sake of providing an example, I have summed the "FY2015 Current", "FY2016 Enacted", and "FY2017 Request" values for the "Carbon Capture" and "Carbon Storage" budget lines as shown on page 566 of 822 in the PDF file. "Carbon Capture" sums to $413,752,000. "Carbon Storage" sums to $293,771,000. The total funding by appropriation for the entire DoE in "FY 2015 Current", "FY2016 Enacted" and "FY 2017 Request" amounts to $89,492,851,000. (See page 7 of 822 in the PDF file.) Therefore, carbon capture and carbon storage R&D funding amounts to about 0.8 percent of the estimated DoE budget for FYs 2015, 2016, and 2017.

I hope this information is of some use to you. Please contact me if I may be of any further assistance.

Tony

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This severe, high temperature service requires that the fuel cell stack be refurbished every five years. FCE has recently developed MCFCs using nickel and stainless steel that can go up to seven years without refurbishment. FCE's modular design allows for removal of the MCFC for refurbishment and replacement with a new MCFC.

"Scaling Up"

If the pilot plant testing is successful, FCE will determine if it can "scale up" using the modified MCFC. Page 11 shows that twelve 280-MW MCFCs would create about a 3-acre footprint (510 feet by 240 feet). This arrangement could be used to capture 90 percent of the CO2 in the flue gas generated by a 35-MW coal-fired EGU, or for a lower CO2 capture rate on a larger coal-fired EGU.

If the MCFC pilot trial at Plant Barry is successful, FCE believes it can achieve a carbon capture cost at or below $40 per metric ton of CO2 captured.

Please review the attachments and contact me if you have any questions.

Thanks,

Tony

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